DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 260

PRELIMINARY REPORT

ON THE

GROUND WATERS OF ESTANCIA VALLEY NEW MEXICO

BY

OSCAR E. MEINZER

WASHINGTON
GOVERNMENT PRINTING OFFICE
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INTRODUCTION.

LOCATION AND AREA.

Estancia Valley lies near the geographic center of New Mexico, south of Santa Fe and east of Albuquerque. The valley is a depression with no drainage outlet. It has a maximum extent of about 65 miles north and south and 40 miles east and west, and includes an area of about 2,000 square miles.

GEOGRAPHIC RELATIONS.

On the west Estancia Valley is separated from the Rio Grande valley by a mountain wall; on the east it is bordered by a maze of hills which divide it from the upland that slopes toward the Pecos Valley; on the north it rises gradually until it ends abruptly as a plateau overlooking the valley of Galisteo Creek, which flows westward into the Rio Grande; on the southwest it is terminated by a mesa; and on the southeast, where it is hemmed in between the mesa and the hills, it is separated by a low divide from another closed basin.

DEVELOPMENT.

This valley has long supported a sparse population. Nestled in the western foothills, remote from any city or railroad, the Mexican villages of Chilili, Tajique, Torreon, Manzano, and Punta de Agua have for generations led a peaceful but primitive existence, their inhabitants depending for a livelihood chiefly on their flocks of sheep. Moreover, planted here and there on the broad, level expanses of the valley proper are isolated establishments which have been the homes of independent and prosperous ranchers, most of whom are Mexicans.

But within the last decade a great change has taken place in this region. Two railways have been built—the Santa Fe Central, which traverses the entire length of the valley, and the "Belen cut-off" of

the Atchison, Topeka and Santa Fe Railway, which crosses its southern part. Hundreds of homesteaders have come to take possession of the land, and eight villages have sprung up along the railways.

INVESTIGATION AND REPORTS.

Insufficient rainfall during recent years has caused crop failures and has created an urgent demand for an investigation of the feasibility of irrigating with ground water. In response to this demand and for the purpose of classifying the land under the enlarged-homestead act, an examination of the valley covering a period of six weeks was made by the writer in the summer of 1909. The time available was not sufficient to permit a thorough investigation. Hence attention was given especially to the more pressing and practical phases of the problem.

A report embodying all the results of the work has been prepared, but this report contains maps and other illustrations which will delay its publication, so that some months must elapse before it will be ready for distribution. In view of the rapid development now under way in the valley and the immediate need of the settlers there for all the definite information that can be supplied, it has seemed desirable to abstract from the complete report the facts and deductions that are of most practical value and to publish them in this brief preliminary paper.

OUTLINE OF THE GEOLOGY.

VALLEY FILL.

The hard rock floor of Estancia Valley is covered by deposits that may be grouped under the general term "valley fill." Nearly all these sediments came originally from the highlands that border the valley and are the product of thousands of years of weathering and denudation. The erosive processes which have carved the canyons and given form to the serrate peaks have at the same time supplied the material that has accumulated in the lowlands as the valley fill.

WORK OF THE STREAMS.

DISTRIBUTION OF THE ALLUVIAL DEPOSITS.

Apparently the bulk of the valley fill consists of alluvial deposits—that is, of materials laid down by streams and not rehandled by any other agency. Such deposits underlie the broad belt comprising the alluvial slopes, are interbedded and intermingled with lake deposits in the littoral zone, as can be seen in many natural and artificial exposures, and probably occur at no great depths below the lake sediments in the lake flat and clay hill area. Their relation to the lake deposits can be best understood after the latter have been described (p. 8).

The alluvial material is much thicker in some localities than in others. If the interpretations of the well sections are correct, the total thickness of the valley fill is 312 feet at Willard, 225 feet in the test wells 4 miles east of Estancia, and 233 feet in H. C. Williams's well south of Estancia. L. Knight's deep well (in the NE. $\frac{1}{4}$ sec. 1, T. 5 N., R. 8 E.) was carried to a depth of 240 feet without encountering rock. In many parts of the valley, however, especially on its east and west margins, the alluvium is much thinner and rock crops out.

ORIGIN OF THE ALLUVIAL DEPOSITS.

The alluvial deposits were laid down by streams which were probably intermittent and exceedingly irregular in their flow, depending then, as now, chiefly on the sudden and capricious visitations of heavy local storms. The work of these streams was correspondingly capricious and variable; at one place they eroded, only to deposit a little farther on the load which they thus picked up; at one place they left behind coarse gravel, and at another they laid down only fine silt. The same locality was at different times subjected to all these conditions and, moreover, by the frequent changing of the courses of the streams, was at one time an arroyo and at another an interstream area. It is therefore not surprising that the alluvial deposits consist of heterogeneous beds which have little continuity or regularity, and that two wells in the same locality should have quite different sections.

CHARACTER OF THE ALLUVIAL DEPOSITS.

Most of the alluvial material consists of clay with which are associated pebbles and bowlders of different sizes and composition. In general the pebbles and bowlders decrease, both in size and abundance, from the mountain borders, where bowlder beds with little or no clay may occur, toward the central portion of the valley, where clay virtually free from pebbles may be found. But though coarse materials form a larger proportion of the mass in the regions near the mountains than in the interior, yet well sections furnish abundant proof that beds of clean gravel and sand occur in the very heart of the valley. The composition of the pebbles depends on the kind of rocks that constitute the uplands and the resistance of these rocks to weathering and wear. On the whole, pebbles of limestone are by far the most numerous, because this rock is well represented in the uplands, especially on the west, and is also resistant in character.

WORK OF THE LAKE.

At its period of greatest extension the lake that occupied the central portion of the valley was about 35 miles long and 23 miles wide and had an area of about 450 square miles. Its maximum depth at this

period was almost 150 feet, and its shore line, which nearly coincides with the 6,200-foot contour, was about 150 miles long. If this lake were now in existence the villages of Estancia and Willard would be 100 feet under water; McIntosh and Progreso would also be submerged; Moriarty and Lucy would virtually be lake ports; and Stanley, Mountainair, and Cedar Vale would be inland towns. The higher ground which surrounded the lake has been explored everywhere, but no outlet channel has been found and it is therefore certain that the lake had no outlet and that its water was salt.

The theory of the existence of an ancient lake in the valley is based on the presence of shore features and lake sediments.

SHORE FEATURES.

Within the littoral zone there are sea cliffs, terraces, beaches, beach ridges, spits, and bars. These features are found on all sides of the lake flat between the altitudes of 6,100 and 6,200 feet above sea level.

LAKE SEDIMENTS.

Beach material.—Most of the material constituting the beaches, beach ridges, spits, and bars is gravel. The pebbles are waterworn and many of them are covered with a gray coat of lime. The best exposures of beach material are found in the gaps that have been cut through the bars.

Stratified sediments.—Except where the salt basins and clay hills occur, the large area inclosed by the shore zone is exceedingly flat; but the salt basins are excavated to depths of 10 to 20 feet and more in the material under this plain, and their sides are generally steep and thus expose the strata to good advantage. Wells have also been dug and these are usually left uncased, showing the materials through which they extend. Moreover, many cellars and dugouts have been made, most of which likewise remain unlined. Ample opportunity is therefore afforded to examine the formation which immediately underlies the plain. This formation is totally different from that which underlies the alluvial slopes. It is perfectly stratified, consisting of innumerable thin layers lying one upon another, each layer traceable for an indefinite distance. It is precisely the kind of deposit which would be formed at the quiet bottom of a large body of standing water and which could be formed in no other manner. It was observed in many exposures, natural and artificial, and in widely separated localities. It is practically coextensive with the lake flat and clay hills area and can be seen wherever there is a salt basin, a dug well, a cellar, or any other excavation.

Clay or shale constitutes the bulk of the material, but layers of sand are also present and beds of grit and fine gravel were observed near the outer margin of the lake flat.

Of the thickness of the lake sediments little is definitely known, but the available evidence indicates that they are relatively thin and are underlain at no great depth by alluvial deposits. The principal evidence concerning their thickness is found in the beds of alluvial gravel encountered in drilling on the lake flat and in the transition in many wells from grayish lake sediments near the surface to alluvial deposits of red clay at greater depths.

WORK OF THE WIND.

On the east side of the valley there are great masses of wind-blown sand, the largest accumulations being found east of McIntosh, in the west-central part of T. 6 N., R. 11 E., and in an adjacent area to the west, and in certain localities both north and south of Progreso. Much of this sand is heaped into fresh dunes and is at present being handled by the winds.

SALT BASINS AND CLAY HILLS.

The salt basins are found in the lowest portion of Estancia Valley. They are not, however, remnants of the ancient lake—not merely low spots in which the surplus water collects until it is dissipated by evaporation—but are distinct basins sunk below the level of the plain by which they are surrounded, and most of them are bordered by definite, nearly vertical walls. Their flat bottoms practically coincide with the ground-water level and generally consist of mud covered with crusts of salt, although after rains they may be submerged in water. The floor of one basin—Laguna Salina, in secs. 29 and 30, T. 5 N., R. 10 E.—is covered with salt sufficiently thick and pure to be commercially valuable.

Altogether there are several score of salt basins with a total area estimated at 13,500 acres. In this assemblage Laguna del Perro assumes relatively gigantic proportions, having a length of about 12 miles and an area nearly equal to the combined area of all the other basins.

Intimately associated with the salt basins are the clay hills. Within the area in which they exist there are many level tracts which are essentially a part of the original plain. The highest clay hills rise more than 100 feet above the plain on which they rest, but most of them are perhaps less than 50 feet high.

Typically they form huge embankments which more or less completely encircle the salt basins. This form is so common that the traveler on approaching a hill or ridge confidently expects to find a salt basin on the other side.

SOILS.

RED LOAMY SOIL.

The most widely distributed soil in the valley consists of red clay intermingled with varying quantities of grit and gravel. It is seen in typical character in the alluvial slopes and arroyos, but it also occurs throughout much of the littoral zone and is found far up in the foothills. It is essentially the product of the weathering of the rocks in the surrounding highlands, whence it has been washed out into its present position in the manner already described. In general this soil is very fertile, as is demonstrated by the large crops that it produces when climatic conditions are not unfavorable, and its fertility is due largely to its content of soluble substances which serve as plant food. These soluble substances have been produced by the weathering of the rocks and have not been leached out from the soil by percolating waters to so great an extent as in more humid regions.

SANDY SOILS.

Sandy soils are found chiefly on the east side of the valley. They range from clean, pale-yellow dune sand, which is worthless for agriculture, to red, earthy sand and red sandy loam, which may be very productive. Sandy soils, like clay and loam soils, have been deprived of less of their soluble constituents in arid than in humid regions.

ALKALI SOILS.

It has just been stated that most of the soil in Estancia Valley, as in arid and semiarid regions generally, is very fertile because of the soluble substance which it contains. But if certain soluble substances, commonly known as alkalies, exist in soils in quantities too large, they are injurious to plant life; hence very fertile soils grade readily into alkali soils; and, moreover, soils which at first are very productive may, after a period of irrigation and cultivation, become harmfully alkaline. On this point Milton Whitney,[a] chief of the Bureau of Soils, United States Department of Agriculture, makes the following statement:

> This accumulation explains the wonderful fertility of the lands generally in the arid regions the world over, but it is also a constant menace because of the large amount of soluble salts which is liable to accumulate locally as the result of irrigation or as a result of other natural conditions not well understood, until they are a menace and often a destructive agency for the very lands which were formerly held in such esteem.

The different kinds of alkali and their effects upon vegetation can best be explained by a further quotation from Whitney, as follows:

> The alkali soils of the West are of two principal classes. The alkaline carbonates or black alkali (usually sodium carbonate) is the worst form, actually dissolving the organic materials of the soil and corroding and killing the germinating seed or roots of

[a] Alkali lands: Farmers' Bull. No. 88, U. S. Dept. Agr., 1899, p. 7.

plants; the white alkalies, the most common of which are sodium sulphate (Glauber's salt), sodium chloride (common salt), magnesium sulphate, and magnesium chloride, are not in themselves poisonous to plants, nor do they attack the substance of the plant roots, but are injurious when, owing to their presence in excessive amounts, they prevent the plants from taking up their needed food and water supply.

The amount of soluble salts which plants can stand depends upon the character of the salt, the character of the soil, and the kind of plant. Hilgard states that few plants can stand as much as 0.1 per cent of sodium carbonate; of sodium chloride plants can stand about 0.25 per cent, and of sodium sulphate 0.45 to 0.5 per cent. Plants can stand less salts in sandy lands than on heavy clay or gumbo lands. It is a well known fact that crops also differ in their ability to stand salts, and many crops will grow well upon soils on which others will not live.

Investigations at Billings, Mont., showed that when the concentration of the salts in active solution in the soil moisture is as great as 1 per cent the limit of most cultivated plants is reached. Further concentration kills all our ordinary agricultural crops. It was found, furthermore, that plants could just exist with 0.45 per cent of the soluble salts present, and this is taken as the limit of plant production.

A later statement by C. W. Dorsey,[a] of the Bureau of Soils, is as follows:

Of the different classes of alkali, sodium carbonate, or black alkali, is considered the most injurious. Laboratory experiments have shown that magnesium chloride and sulphate are as injurious, if not more injurious than sodium carbonate. After these salts comes sodium chloride (ordinary salt) and sodium sulphate. When present in soils to the exclusion of other salts, 0.05 per cent of sodium carbonate presents about the upper limit of concentration for common crops. One-half of 1 per cent of sodium chloride is commonly regarded as the endurance limit of crops, and 1 per cent of sodium sulphate. Sodium sulphate, then, is the least injurious and sodium carbonate the most injurious of the salts usually constituting the greater part of alkali under ordinary field conditions, while sodium chloride occupies a middle position.

Gypsum (calcium sulphate) acts as an antidote for black alkali by reacting with it to form (1) calcium carbonate, which is harmless, and (2) sodium sulphate, which is a less injurious white alkali. A soil that contains a large amount of gypsum would therefore not be expected to contain much black alkali, although it may contain some.[b]

In Estancia Valley the shallow-water belt, the ancient lake bed, the area of highly mineralized waters, and the area in which the most alkaline soils are found all coincide approximately with one another, because all are results of the same general causal conditions. The rain that falls on the highland borders naturally flows toward the lowest area, where it accumulates until it is disposed of by evaporation. Whether it here stands slightly below the general surface of the ground, as at present, or a short distance above the surface, as during the Pleistocene epoch, when a lake existed, is merely an incident in the general circulation. The important facts in this con-

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[a] Reclamation of alkali soils: Bull. Bureau of Soils No. 34, U. S. Dept. Agr., 1906, p. 10.

[b] Cameron, F. K., Application of the theory of solution to the study of soils: Field operations, Div. of Soils, 1899, U. S. Dept. Agr., 1900, pp. 152 et seq. Hilgard, E. W., Soils, Macmillan Co., New York, 1906, pp. 449 et seq., 457, 458.

nection are that in its course it dissolves and carries along the soluble constituents which it encounters in the rocks and soil, and that on its evaporation these soluble constituents are left behind, thus becoming concentrated in the lowest portion of the valley. The crusts of alkali which cover the salt basins are visible illustrations of the process that has impregnated with alkali the soil of the low area.

Samples of soil were collected at five points within the lake flat along a line extending eastward from Estancia for a distance of 6 miles, and these samples were analyzed by the United States Bureau of Soils with the following results:

Analyses of soil in Estancia Valley.

Location.	Depth within which the material was obtained.	Soluble solids (alkalies), per cent of total material.	Predominating salts in the order named.
	Feet.		
Estancia, NW. ¼ sec. 12, T. 6 N., R. 8 E., at the intersection of the railway with the section line.	1	0.2	Chlorides and bicarbonates.
	2	.3	Do.
	3	.8	Sulphates and chlorides.
	4	1.0	Do.
	5	1.2	Do.
	6	1.0	Do.
T. J. Moore, northeast corner of SW. ¼ sec. 5, T. 6 N., R. 9 E.	1	.1	Do.
	2	1.4	Chlorides and sulphates.
	3	1.3	Sulphates and bicarbonates.
	4	1.5	Do.
	5	2.1	Sulphates and chlorides.
	6	1.6	Do.
Southwest corner of sec. 4, T. 6 N., R. 9 E.	1	.6	Do.
	2	.7	Chlorides and sulphates.
	3	3.7	Sulphates and chlorides.
	4	3.9	Do.
	5	3.7	Do.
	6	3.5	Do.
N. Williams, southwest corner of SE. ¼ sec. 3, T. 6 N., R. 9 E.	1	2.5	Do.
	2	2.7	Do.
	3	2.9	Do.
	4	2.7	Do.
	5	2.9	Do.
	6	3.5	Do.
H. N. Summers, southeast corner of SW. ¼ sec. 1, T. 6 N., R. 9 E.	1	1.6	Do.
	2	2.8	Do.
	3	3.7	Do.
	4	4.5	Do.
	5	3.6	Do.
	6	4.5	Do.

In respect to these analyses J. A. Bonsteel, in charge of soil surveys, writes:

It is apparent to the student of soils and soil conditions in the basin region that these soils are very heavily loaded with alkali salts, comparing more directly with those of old desiccated lake basins than with any of the agricultural lands now occupied in the United States. You will also notice the continual appearance of chlorides in practically all of the samples. From this I judge that the soil samples were taken from a decidedly alkaline tract, probably a desiccated lake bed. Only the most efficient tile underdrainage would render the majority of these soils capable of producing crops.

WATER.

SOURCE AND DISPOSAL.

If the mean annual precipitation for the entire Estancia basin is assumed to be 15 inches, the total amount of water that falls as rain or snow in an average year on the basin is approximately 1,600,000 acre-feet. If it is further assumed that within recent years the quantity of ground water has not materially increased nor decreased, it follows that the same amount is, on the average, withdrawn each year from the Estancia basin. This withdrawal is accomplished by evaporation into the atmosphere and by seepage through underground passages to lower points outside of the basin. No water leaves the basin in surface streams.

EVAPORATION FROM THE SURFACE.

Much of the water that falls as rain or snow returns to the atmosphere by being evaporated, either directly from the surface before it soaks into the ground or else after it has soaked a short distance into the ground, from which it is again withdrawn by vegetation or by capillary action in the soil. The proportion of moisture thus disposed of is greatest for the lightest showers and least for the heaviest and most persistent rains.

MOUNTAIN SPRINGS AND STREAMS.

Some of the moisture that falls on the mountains seeps into the pores and crevices of the rocks, but reappears at lower levels, where it issues in numerous springs that give rise to brooks or rivulets, most of which disappear long before they reach the valley, the water being dissipated both by evaporation and by seepage into the ground. Springs and streams of this type in the canyons and foothills of the Manzano Range have determined the location of the old Mexican settlements of Chilili, Tajique, Manzano, Punta de Agua, Torreon, and the settlement south of Torreon.

FLOODS.

In the entire basin there are no permanent streams except the tiny ones just mentioned, but there are many wide stream channels, or arroyos, which are normally dry but which during heavy storms carry water. The water of most of these floods is lost in the arroyos, but that of a few of the largest reaches the central flat and there soaks into the earth. Probably these floods furnish most of the ground water in the valley fill.

UNDERFLOW.

Though the valley includes no important permanent surface stream it contains a great body of ground water which, below a certain depth,

fills every pore, crack, and crevice. From time to time this great body of water receives contributions from portions of the rainfall that escape evaporation. It is not, however, a stationary mass, for it moves constantly though very slowly away from the upland border and toward the low central portion of the basin.

OVERFILLING OF UNDERGROUND RESERVOIR.

If the ground water is constantly augmented by contributions from the rainfall, and if this newly acquired water moves constantly toward the center of the valley, it would be expected that in the central region the pores and crevices of the ground above the bed rock would eventually all become filled and the underground reservoir would overflow. This is essentially what takes place, the surplus being returned to the surface or brought so near to the surface that it can be reached by evaporation. The surplus is disposed of in three ways—(1) by overflow from valley springs; (2) by evaporation from the salt basins; and (3) by evaporation directly from the ground water wherever it rises near enough to the surface to come within the reach of the atmosphere through capillarity. In each of the three ways the ground water is returned to the atmosphere by evaporation.

Where the ground water lies sufficiently near the surface it is withdrawn in the same manner and by the same process that kerosene is withdrawn through the wick of a burning lamp. The soil is the wick. The moisture at the top of the soil is constantly being removed by evaporation just as the kerosene at the top of the wick is removed by burning, and new moisture is drawn up through the pores of the soil just as new kerosene is drawn up through the pores of the wick. In both cases the liquid is lifted by capillarity. But the height to which a liquid can be thus raised is greater for small pores than for large ones. Thus, water can be lifted higher, although less rapidly, in a clay soil, which has small pores, than in a sandy soil, which has large pores.

It is not now possible to make an estimate of the height to which capillarity is effective in the soils of Estancia Valley or of the quantity of water withdrawn from the underground store by this process, but the quantity is undoubtedly large. Near the McGillivray well in Estancia, where the ground water is only about 5 feet below the surface, incrustations of salt were observed, although similar incrustations were not seen in places in the same locality where the depth to ground water is greater. Incrustations are not found on the red soil that lies at a higher level to the west nor, as a rule, on the "ashy" soil which lies at a lower level to the east. East of Moriarty, also, there are areas in which water lies at shallow depths and which show traces of salt at the surface, such as are not generally found in the central part of the valley. The explanation seems to be that in areas where

the depth to ground water is slight the water is drawn to the surface, where it evaporates and leaves its content of salt. (See discussion of quality of the water, pp. 17–23.)

GROUND-WATER TABLE.

Over an area of about 240 square miles (including the salt basins) the ground water stands within 25 feet of the surface; over an area of about 210 square miles it stands between 25 and 50 feet below the surface; and over an area of about 250 square miles it stands between 50 and 100 feet below the surface. Thus over a total area of about 450 square miles it is less than 50 feet below the surface, and over a total area of at least 700 square miles it is less than 100 feet below the surface. The area in which it lies less than 50 feet below the surface includes the low central plain and extends far up the large arroyos, especially Arroyo Mesteno.

RECOVERY OF GROUND WATER.

In the foregoing pages it has been shown that the ground water constantly receives new supplies on the high land and that it migrates slowly but constantly toward the valley, where the excess is disposed of by evaporation. On its way a small amount is at present intercepted and pumped to the surface. The practical question is, To what extent can the water be thus recovered for use? Two phases of this question will here be considered—(1) the yield of wells and (2) the total amount of water available.

YIELD OF WELLS IN THE VALLEY FILL.

A large amount of miscellaneous information in regard to the yield of wells was collected, but unfortunately the bulk of this information is of little value because few wells have been sunk deep enough to reach the best water horizons, and most of the pumping tests have not exceeded a few gallons a minute. Several rather conclusive tests were, however, reported, and, through the generous assistance of R. B. Cochran, of Estancia, a few others were made in the course of this investigation.

Throughout most of the valley there is no difficulty in obtaining a supply that is ample for domestic and stock uses, but in a few localities even this amount is hard to obtain. Near the north end of the valley no wells were seen, and the prospects of procuring water except at considerable depths are not encouraging. In general, the yield of wells appears to be better on the west side than on the east side of the valley.

At Willard the Atchison, Topeka and Santa Fe Railway Company has drilled a number of wells. The deepest one entered red sandstone

at 312 feet and was continued in this rock to 440 feet, at which depth the drilling was stopped. Within the first 312 feet there were numerous beds of coarse gravel that supplied water freely. Fourteen 8-inch wells were sunk at intervals of about 120 feet to depths of approximately 200 feet. An air lift was applied to twelve of these wells simultaneously for ten days and nights, practically without stopping, and during this period each well yielded 110 gallons a minute and the water level was temporarily lowered 3 feet.[a] The water is used extensively on locomotive engines and for other purposes, train loads being shipped to points more than 50 miles east. Altogether, the consumption from these wells amounts to about 350,000 gallons a day or 400 acre-feet a year.

On the premises of Mrs. McGillivray, in Estancia, two test wells were put down—a 6-inch well to a depth of 37 feet and a 10-inch well to a depth of 233 feet ending in hard rock. According to the driller, the largest supply of water was found at a depth of 33 feet, where the drill entered a 4-foot bed of gravel, from which the water rose to a point 5 feet below the surface. With a suction pipe extending 16 feet below the water level, the 6-inch well was successfully pumped at a rate approximately 200 gallons a minute.

In the test wells 4 miles east of Estancia the most water was found, according to J. L. Mayo, the driller, in a bed of gravel at a depth of about 215 feet, but when the well was pumped at the rate of 15 gallons a minute the level of the water in the well was considerably lowered. The well of Oscar Hadley, 3 miles north and 4 miles east of Estancia, which is 94 feet deep, is reported to have been tested at about 20 gallons a minute without lowering the water perceptibly. The well of B. W. Honnold, in the SE. ¼ sec. 21, T. 7 N., R. 9 E., which is 140 feet deep, is reported to have been tested at 18 gallons; the 6-inch well of P. M. Rutherford, in the SW. ¼ sec. 27 in the same township, which is 104 feet deep, at 40 gallons; the well of Mr. Campbell, about 5 miles northeast of Estancia, at 40 gallons; and other tests of this kind were reported. On a number of the old ranches water has in the past been pumped from wells with steam engines.

AVAILABLE QUANTITY OF GROUND WATER.

The rate at which wells will yield water is a factor of vital importance in determining the feasibility of recovering ground water on a large scale, but, contrary to the general supposition, it gives little information as to the total quantity available. This quantity is not inexhaustible, as is so freely assumed, but the amount that can be obtained by large pumps, such as are required for extensive irrigation, is sharply limited. The quantity of ground water obtainable can

[a] The data in regard to the test were given by John Knowles, who has charge of pumping tests and construction for the railway company.

not be determined by pumping a few hundred gallons a minute from a well for a short period for the same reason that the quantity of water in a lake can not be determined by applying to it the same pump; and to proceed on the theory that any amount of ground water is available for irrigation is even less wise than to plan an irrigation project without reference to the flow of the stream on which it depends. The essential difference is that the flow of the stream can be readily and accurately measured, but no such precise methods can be applied to ground water, and therefore much more caution must be used in carrying out a project that depends upon ground water.

Some idea of the total quantity of water that is stored underground can be obtained by considering the sections of wells that have been drilled. The average thickness of the water-bearing beds can be multiplied by the total area over which they occur, and this product by the percentage of pore space in the material comprising these beds, but such an estimate will give little information that is of practical value because withdrawals in excess of the new contributions will lower the water level, increase the cost of pumping, and eventually lead to disaster. Estimates of possible annual recovery by man must therefore be based on the annual increment or on the surplus annually disposed of by nature, and not on the total quantity now stored in the earth.

Unfortunately the quantity of water that is annually available in Estancia Valley can not be accurately determined. From the discussion under the heading "Source and disposal" (p. 13), it appears that the surplus now disposed of by nature through evaporation from the salt basins and other areas of shallow water is a substantial quantity. It is difficult to conjecture what percentage of this surplus it would be possible to intercept in wells and to pump to the surface. It can hardly be hoped that more than this surplus is annually available.

QUALITY OF THE WATER.

DISSOLVED SOLIDS.

The rocks which lie near the surface are exposed to weathering agencies that disintegrate and decompose them, thereby forming certain mineral compounds that are more or less soluble in water. The water which falls as rain contains little or no dissolved mineral matter, but when it enters the ground and percolates through the earth it gradually takes into solution those soluble substances with which it comes into contact, and thus it is that ground water always contains dissolved mineral matter. As long as this matter is in solution it is invisible, but when the water is evaporated, as in a teakettle or steam boiler or on the surface of the salt basins in Estancia

Valley, it is left behind and forms a crust or scale. Ground waters differ greatly in the total amount of substances they contain in solution and also in the proportions of the different kinds of substances. When, by evaporation of the water or some other cause, these substances are thrown out of solution, they form mineral salts, such as calcium carbonate (limestone), calcium sulphate (gypsum), sodium carbonate (black alkali), sodium sulphate (Glauber's salt), and sodium chloride (common salt).

METHODS OF INVESTIGATION.

During the progress of the field work 84 samples of water were collected and examined for their content of the carbonates, bicarbonates, sulphates, and chlorides. They were chosen from wells or other sources which would aid most in interpreting the quality of the ground water for the entire region. Thus they were obtained from all parts of the valley, but were taken in largest numbers in the central area, where the mineral content varies greatly within short distances and where its consideration is important in connection with irrigation. The assays were made in the field by means of the apparatus and methods described in Water-Supply Paper 151. In order to have some check on the work, and also to have a basis for judging the relative amounts of calcium, magnesium, sodium, and potassium, a single sample was sent to Prof. J. R. Bailey, of the University of Texas, for complete analysis in the laboratory. This sample was taken from the well of H. N. Summers, 6 miles east of Estancia, in the region where it was especially desirable to know the relative amounts of mineral substances in the deeper waters. The following table gives the complete analysis, and for purposes of comparison the field assay of a sample taken from the same well on the same day:

Analysis and field assay of water from well of H. N. Summers, 6 miles east of Estancia.

Ions.	Parts per million.	
	Sample assayed in the field.	Sample analyzed in the laboratory.
Silica (SiO_2)		19
Iron (Fe)		.05
Aluminum (Al)		Trace.
Calcium (Ca)		200
Magnesium (Mg)		114
Sodium (Na)		274
Potassium (K)		3.8
Carbonate radicle (CO_3)	0.0	.0
Bicarbonate radicle (HCO_3)	243	306
Sulphate radicle (SO_4)	553	755
Chlorine (Cl)	393	390
Total solids		1,956
Temporary hardness as $CaCO_3$		251
Free carbon dioxide (CO_2)		8.8

The field determination agrees closely with the laboratory analysis in the content of chlorine, but there are considerable discrepancies in the bicarbonate and sulphate determinations. The bicarbonate determination is a simple volumetric process with a definite end point, and the assays probably gave results that are fairly accurate relative to each other. Despite these discrepancies, the field assays are of value, especially in throwing light on the problem of the utility of the water for irrigation, a problem in which it is desirable to have tests from as many localities as possible, but in which great precision is not required.

The table on pages 22–23 presents the results of the 84 field assays.

CHLORINE.

In general the chlorine content of these waters is proportionate to the amount of common salt that would be deposited by their evaporation. The ground waters of Estancia Valley differ widely in this respect, the samples analyzed ranging from 7 parts to 16,442 parts per million in the amount of chlorine that they contain.

The analyses show the following conditions: (1) That the water underlying the western slope (including nearly all of the western alluvial slope and most of the littoral zone) contains small quantities of common salt, the chlorine content being uniformly less than 25 parts per million; (2) that in this large area the amount of salt does not increase notably from the foothills toward the center; (3) that throughout a small area in the center of the valley the chlorine content is very great, some of the shallow water being so salty that it can not be used for watering stock; (4) that between the first and the second area there is a zone of fairly pure water which averages about 3 miles in width but which has a tendency to extend some distance up the arroyos; and (5) that on the east side of the valley the water is somewhat higher in its content of salt than on the corresponding west slope. The transition from the fairly pure water of the intermediate zone to the strongly saline water in the central area is remarkably abrupt; so that on the west side, where there are many wells, it is possible to outline with some definiteness the limits of the area in which the water has more than 1,000 parts of chlorine. The abruptness of this transition is shown by assay No. 59 (J. B. Striplin) and assay No. 61 (J. W. Kooken), given in the table (p. 23). The first sample, coming from a well that is in the intermediate area, showed only 219 parts of chlorine; the second, taken from a well a quarter of a mile farther east, showed 5,276 parts.

In the central area the shallowest water is the most strongly saline, and the water from deeper sources is, as a rule, much better. However, no definite law of variation with depth could be established, and it is altogether probable that in some of the deeper wells a certain

amount of shallow water is admitted by imperfect casing and mingles with the deep water that forms the principal supply. Within the area in which the shallow water contains more than 1,000 parts, 9 samples were taken from cased wells in which, so far as could be ascertained, the water came from more than 25 feet below the ground-water level. In these 9 samples the chlorine content ranged from 234 parts to 932 parts and averaged 595 parts, whereas 6 samples of shallow water within the same area ranged from 1,165 parts to 16,442 parts and averaged 7,063 parts, or more than 12 times as much as in the deeper waters.

Finally, it is important to note that the deep waters in the central area are much saltier than the waters from wells on the surrounding slopes. Thus, 34 samples were taken on the west side in the area of less than 25 parts per million, which includes nearly all of the extensive region lying west of the Santa Fe Central Railway. In these 34 widely distributed samples the chlorine content ranged from 7 to 25 parts and averaged 16 parts, a result which should be compared with that of the assays of the 9 samples of deep waters in the central area in which the chlorine ranged from 234 to 932 parts and averaged 595 parts, or 37 times as much.

CAUSE OF SALINITY.

The salinity of the water in the central area results from the process described under "Source and disposal." The ground water is constantly being replenished at the borders by rainfall; responding to the force of gravity, it constantly moves valleyward; and in the low central area the accumulating surplus is constantly coming to the surface and being disposed of by evaporation. In its migration through the earth it picks up a load of salt which it takes into solution, and when it evaporates it leaves this salt behind, thus adding to the salinity of the remaining water or to the amount of alkali in the soil.

But the precise reason for the existing conditions is not so evident. In most of the area in which the sheet of saline water occurs the ground-water level is too far below the surface for capillarity to be effective in drawing up ground water within the reach of evaporation. Thus, in the wells from which were taken the 6 samples that were tested, the depth to water ranges from 7 to 36 feet, and capillarity is probably not effective for depths of more than 5 feet and quite certainly not for depths of more than 10 feet. Moreover, the salts drawn up by capillary action would be deposited near the surface where evaporation would occur, and it is not obvious how they would be carried back so as to contribute to the salinity of the ground water. It is also necessary to account for the salt content in the deeper waters at the center. The most reasonable hypothesis is

that at various horizons in the valley fill of the central area there are beds which are impregnated with salt that was deposited by evaporating waters at the time they were formed, and that afterward these beds became buried under new accumulations of valley fill. It is not unlikely that the shallow sheet of brine coincides approximately with a buried salt deposit laid down at the bottom of the ancient lake at a certain stage of its existence. This hypothesis will also explain the sharp boundary of the area.

EFFECT OF DISSOLVED SOLIDS.

Small amounts of the constituents commonly found in natural waters are not harmful to health. Chlorides are not objectionable in drinking water if only 50 to 100 parts per million are present, but amounts clearly perceptible to the taste render water unpalatable. Magnesic or sodic sulphated waters are laxative, and excessive magnesium or sodium content renders water unfit for man and beast. The worst form of alkali water—that containing alkaline carbonates—was not found in this region.

Calcium and magnesium render water hard and therefore poor for toilet and laundry uses. Bicarbonate and an equivalent quantity of calcium and magnesium are removed from water by boiling, but the calcium and magnesium in excess of this amount, such as would be present in gypsiferous waters, can not be precipitated by boiling. Sodium and potassium do not consume soap and therefore do not make water hard.

Water containing relatively large amounts of most kinds of dissolved mineral matter is tolerated by plants. Among the common sodium salts, the most injurious is sodium carbonate and the least injurious is sodium sulphate; sodium chloride occupies an intermediate position. The effect of dissolved solids in irrigation water is more fully discussed under the next heading—"Irrigation."

Chemical analyses of water in Estancia Valley.

[Field assays. Parts per million unless otherwise stated.]

No.	Owner.	Location.	Description of well.	Depth of well.	Depth to water.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).[a]	Chlorine (Cl).
				Feet.	*Feet.*				
1	Cedar Vale well	SW. ¼ sec. 27, T. 2 N., R. 12 E.	Drilled, partly cased	298	174	0	424	>625	55
2	Mountainair village well	Mountainair	Drilled	303		0	212	157	9
3	Elijah Bradley	NE. ¼ sec. 11, T. 3 N., R. 9 E.	do	100	80	0	170	>625	25
4	Progreso well	SW. ¼ sec. 15, T. 3 N., R. 10 E.	Dug		35	0	158	574	33
5	J. S. Penny	NE. ¼ sec. 1, T. 4 N., R. 6 E.	do	50	45	0	206	<30	13
6	S. R. Seymour	SW. ¼ sec. 8, T. 4 N., R. 7 E.	Drilled	110	55	0	170	<30	17
7		NE. ¼ sec. 11, T. 4 N., R. 7 E.	do	150	110	0	218	<30	13
8	J. B. Vincent	NE. ¼ sec. 23, T. 4 N., R. 8 E.		95	93	0	194	160	24
9	E. P. Parker	NE. ¼ sec. 24, T. 4 N., R. 8 E.	Dug		63	0	146	146	20
10		SE. ¼ sec. 24, T. 4 N., R. 8 E.	do		66	0	158	181	18
11	W. R. Walden	NE. ¼ sec. 26, T. 4 N., R. 8 E.	do	120	105	0	158	181	18
12	Ranch	NE. ¼ sec. 32,[b] T. 4 N., R. 8 E.				0	121	>625	25
13	Eugene Forbes	SE. ¼ sec. 6, T. 4 N., R. 9 E.	Dug	40	40	0	194	197	31
14	Atchison, Topeka & Santa Fe Ry. wells at Willard.	NW. ¼ sec. 8, T. 4 N., R. 9 E.				0	218	238	46
15		NW. ¼ sec. 11, T. 4 N., R. 9 E.	Dug		8	0	291	>625	417
16	A. P. Hanna	NW. ¼ sec. 31, T. 4 N., R. 9 E.	do	98	85	0	109	>625	17
17	Ranch	SW. ¼ sec. 3, T. 4 N., R. 10 E.	do		30	0	412	>625	1,165
18		Sec. 33,[b] T. 4 N., R. 10 E.				0	133	383	40
19	J. B. Teague	SE. ¼ sec. 17, T. 5 N., R. 7 E.		115	93	0	230	<30	9
20	Ranch	SW. ¼ sec. 33, T. 5 N., R. 7 E.	Dug		15	0	327	35	17
21	L. Knight	NE. ¼ sec. 1, T. 5 N., R. 8 E.	Large dug hole	27	20	0	243	80	15
22	Thomas Elgin	SW. ¼ sec. 6, T. 5 N., R. 8 E.	Dug		82	0	182	<30	7
23		NE. ¼ sec. 35, T. 5 N., R. 8 E.	do		31	0	267	42	15
24		NE. ¼ sec. 18, T. 5 N., R. 9 E.	6-inch, with casing	36	24	0	545	478	65
25	E. L. Moulton	SE. ¼ sec. 13, T. 5 N., R. 10 E.	Drilled and cased	120	95	0	121	>625	141
26	Fletcher Brown	SW. ¼ sec. 4, T. 5 N., R. 11 E.	Drilled with casing	84	65	0	340	406	261
27	Stream	Sec. 26,[b] T. 6 N., R. 6 E.					158	<30	10
28	Spring in foothills	Sec. 34,[b] T. 6 N., R. 6 E.				0	388	<30	7
29	Porter ranch	SW. ¼ sec. 34, T. 6 N., R. 7 E.		125	100	0	218	<30	7
30	L. C. Weaver	NW. ¼ sec. 1, T. 6 N., R. 8 E.	Not cased	40	26	0	679	328	140
31	R. B. Cochran	SW. ¼ sec. 11, T. 6 N., R. 8 E.	Dug		13	0	267	<30	5
32	Estancia Spring	SE. ¼ sec. 11, T. 6 N., R. 8 E.				0	291	<30	17
33	Box factory, Estancia	NW. ¼ sec. 12, T. 6 N., R. 8 E.	Cased to 59 feet		20	0	873	>625	251
34	W. J. Adair	NW. ¼ sec. 12, T. 6 N., R. 8 E.	Dug		18	0	631	574	693
35	Valley Hotel, Estancia	SW. ¼ sec. 12, T. 6 N., R. 8 E.				0	320	383	54
36	N. E. Bilsing	SE. ¼ sec. 13, T. 6 N., R. 8 E.		12	9	0	243	344	84
37	H. C. Williams	NE. ¼ sec. 26, T. 6 N., R. 8 E.	Dug		6	0	243	50	20
38		NE. ¼ sec. 26, T. 6 N., R. 8 E.	Drilled and cased	318	4	0	533	66	139
c39	H. N. Summers	SW. ¼ sec. 1, T. 6 N., R. 9 E.	3-inch casing to 45 feet	65	10	0	243	431	438
c40						0	243	553	393

41	N. Williams	SE. ¼ sec. 3, T. 6 N., R. 9 E.	Cased	26	9	0	364	>625	914
42	T. J. Moore	SW. ¼ sec. 5, T. 6 N., R. 9 E.	Dug		13	0	340	383	80
43	Mrs. N. L. Williams	NE. ¼ sec. 10, T. 6 N., R. 9 E.	Cased	32	7	0	303	>625	15,075
44	Unsuccessful test well	SW. ¼ sec. 10, T. 6 N., R. 9 E.	Cased to 205 feet	215	7	0	533	553	784
45	A. Abbott	SE. ¼ sec. 11, T. 6 N., R. 9 E.	Cased to 100 feet	159	5	0	243	328	309
46	Charles May	NE. ¼ sec. 12, T. 6 N., R. 9 E.	Dug	20	20	0	259	>625	16,442
47	A. Abbott	SE. ¼ sec. 15, T. 6 N., R. 9 E.	Cased to 120 feet	156	6	0	424	553	603
48		SW. ¼ sec. 15, T. 6 N., R. 9 E.	do	156	5	0	582	553	932
49	J. J. Smith	NW. ¼ sec. 19, T. 6 N., R. 9 E.	Drilled, 6-inch casing	60	8	0	315	91	40
50	W. H. Hancock	NE. ¼ sec. 20, T. 6 N., R. 9 E.	Drilled and cased	90		0	679	>625	603
51	C. B. Cornell	SW. ¼ sec. 28, T. 6 N., R. 9 E.	Not cased	18	14	0	728	>625	269
52	A. L. Bilsing	N. ½ sec. 33, T. 6 N., R. 9 E.	Drilled and cased	100	14	0	752	>625	587
53	William Dunbar	Sec. 4,[b] T. 6 N., R. 10 E.		50	47	0	194	553	283
54		Sec. 26,[b] T. 6 N., R. 10 E.	Dug		36	0	218	>625	2,412
55	E. F. Heal	SE. ¼ sec. 31, T. 6 N., R. 11 E.	do	60	50	0	194	492	361
56	J. B. Gwaltney	SE. ¼ sec. 36, T. 7 N., R. 7 E.	Drilled	139	135	0	170	<30	13
57	Antelope Spring	SW. ¼ sec. 14, T. 7 N., R. 8 E.				0	364	<30	20
58	M. Freilinger	SW. ¼ sec. 24, T. 7 N., R. 8 E.	Dug		35	0	340	42	55
59	J. B. Striplin	SE. ¼ sec. 20, T. 7 N., R. 9 E.	Dug		10	0	267	265	219
60	B. W. Honnold	SE. ¼ sec. 21, T. 7 N., R. 9 E.	Drilled and cased	140	12	0	243	383	234
61	J. W. Kooken	NW. ¼ sec. 28, T. 7 N., R. 9 E.	Not cased		10	0	680	>625	5,276
62	T. J. Curtis	SE. ¼ sec. 30, T. 7 N., R. 9 E.	Dug		10	0	352	287	85
63	Duncan McGillivray	NE. ¼ sec. 8, T. 7 N., R. 10 E.	Drilled	93	56	0	133	150	40
64	E. F. Moore	SW. ¼ sec. 15, T. 7 N., R. 10 E.			66	0	170	256	65
65	Allan McGillivray	Sec. 31, T. 7 N., R. 11 E.	Drilled	120	45	0	97	>625	60
66	S. C. Keehnel	SE. ¼ sec. 36, T. 8 N., R. 7 E.		140	85	0	279	30	25
67		NW. ¼ sec. 1, T. 7 N., R. 8 E.	6-inch, not cased		30	0	315	43	25
68	John T. Lee	NW. ¼ sec. 28, T. 8 N., R. 9 E.	Not cased	25	22	0	218	460	319
69	J. O. Justus	SW. ¼ sec. 33, T. 8 N., R. 9 E.	do	25	20	0	291	>625	2,010
70	Ranch	SE. ¼ sec. 8,[b] T. 9 N., R. 8 E.			34	0	194	<30	10
71	Michael T. Moriarty	NE. ¼ sec. 22, T. 9 N., R. 8 E.	Dug	32	21	0	218	82	301
72	W. C. Maurer	NW. ¼ sec. 1, T. 9 N., R. 9 E.	Drilled	70	63	0	158	460	274
73	Robert Hickman	SE. ¼ sec. 4, T. 9 N., R. 9 E.	Not cased	30	26	0	170	460	251
74	Edith B. Rush	SW. ¼ sec. 29, T. 9 N., R. 9 E.	Dug		16	0	206	574	222
75	B. Hill	NW. ¼ sec. 28, T. 9 N., R. 10 E.	Drilled	189		0	194	197	20
76	A. Stewart	NW. ¼ sec. 21, T. 10 N., R. 8 E.	do		127	0	206	<30	10
77	R. H. Harper	NE. ¼ sec. 34, T. 10 N., R. 8 E.	do	100	74	0	194	34	15
78	S. F. Kelly	NW. ¼ sec. 3, T. 10 N., R. 9 E.	do		99	0	194	61	13
79	John H. Cantwell	NW. ¼ sec. 5, T. 10 N., R. 9 E.	do	103	75	0	170	95	13
80	E. H. Clayworth	SW. ¼ sec. 27, T. 10 N., R. 9 E.	Dug		27	0	146	383	119
81	G. W. Hearte	NE. ¼ sec. 5, T. 10 N., R. 10 E.		180	165	0	243	56	14
82	Deserted ranch	SW. ¼ sec. 1, T. 11 N., R. 8 E.	Dug	250	200	0	182	78	8
83	Stanley village well	Stanley		160	152	0	230	52	13
84	W. C. Asher	do	Drilled	207	100	0	243	94	18

[a] > = more than; < = less than. [b] Approximate location. [c] Samples 39 and 40 were taken from the same well, but at different times and after different rates of pumping.

IRRIGATION.

Much of the water that falls as rain is lost or is of very small service in agriculture. If only a small part of this water that is now lost can be recovered and applied to growing crops it will greatly increase the agricultural product of the valley. Recovery is possible in two ways—(1) by storing storm water, (2) by pumping ground water. The storage of storm water is not here considered.

UTILIZATION OF GROUND WATER.

PRESENT DEVELOPMENT.

At the time the valley was visited (the summer of 1909) little had been accomplished in the way of irrigating with ground water, although a number of gardens and other small plats were being irrigated from this source by means of windmills, and somewhat more ambitious projects were being undertaken by S. Spore, L. Knight, E. A. Von de Veld, and H. C. Williams.

POSSIBILITIES OF FUTURE DEVELOPMENT.

The data already given seem to indicate that, without seriously depleting the present supply, enough water can annually be withdrawn from the underground reservoir to increase materially the total production of the valley, but that, on the other hand, however economically such water may be applied, it is not sufficient in amount to irrigate more than a small part of the total acreage of arable land. If it is once proved that pumping for irrigation is feasible and profitable, the danger of overdevelopment will become imminent.

PROPER TYPE OF IRRIGATION SYSTEMS.

Irrigation with surface water has necessitated large cooperative projects, but the problem of irrigating with ground water, even on a large scale, is essentially different. In Estancia Valley each farmer should develop his own supply, install his own pumping plant, and construct his own reservoirs and system of distribution. This method of development will insure a maximum supply with a minimum lowering of the head, and will involve the least lift and the least loss in distribution. The only respect in which cooperation may be found profitable will be in installing a central power plant.

PROPER TYPES OF WELLS.

Where large supplies are required, as for irrigation, they can best be obtained by drilling in search of thick beds of clean, coarse gravel that will yield freely, if necessary, sinking at least to the bottom of the

valley fill. There are three reasons why deep drilled wells are likely to yield much more water than shallow wells that stop a short distance below the ground-water level: (1) The thickest and best beds of gravel may occur at great depth; (2) of two similar beds the one at a considerable depth below the ground-water level is likely to yield much more than the one only slightly below this level, because the water in the deeper bed is under much greater artesian pressure; (3) if a deep well is properly finished with perforated casing, it can simultaneously receive supplies from all water-bearing beds that it penetrates.

If a single well will not yield enough, a group of wells can be drilled. A large pump can then be inserted at the bottom of a centrally located pit dug to the ground-water level, or somewhat lower, and suction pipes from all the wells can be connected with it; or, if it is desired to use a chain and bucket elevator, the central pit can be sunk to a considerable depth below the ground-water level and the drilled wells can be connected by horizontal tunnels or pipes with the bottom of the pit, into which they will then discharge. Since the cost of pumping increases with the lift, it will be economy to have so many wells that the water in them will not be greatly lowered by pumping. In either system above described some expense will be involved in connecting the various wells.

For large supplies, beds of very fine sand should be cased out, because this sand yields its water slowly and causes trouble by rising in the wells. Screens can be employed to shut out the sand, but they are liable to become clogged in a short time and to require much attention. Difficulty with sand in wells can be brought to a minimum by pumping slowly or by having a large number of wells so connected that water is drawn only slowly from each.

Where no satisfactory water-bearing bed can be found and where the shallow water is not saline it may be possible to obtain valuable supplies from large dug wells or from systems of infiltration galleries, or it may be feasible to bring up the total yield by combining these with deep wells. If possible the maximum yield of the system of wells should be kept much greater than the capacity of the pumps, as this will reduce to a minimum the cost of lifting the water, the wear and tear of the machinery, and in some places the deterioration of the wells.

GRAVITY INFILTRATION DITCHES.

The fact that it is possible to lead water by gravity from the shallow-water belt on the west side out upon lower ground to the east makes this scheme for irrigation appear very attractive, but it is not believed that enough water can be recovered in this way to justify the necessary expense of construction. The same money will be better

invested in wells and a pumping plant with which a larger, more reliable, and more elastic supply can be obtained. Professor Slichter discusses ditches of this type and makes the following concluding statements: [a]

It should be noted that very few infiltration or underflow canals are in actual use for irrigation. Many pumping plants in use for irrigation have turned out to be both practicable and financially profitable, but the attempts to procure ground water by gravity have usually proved disappointing, and there are numerous abandoned underflow canals in many parts of the West.

COST OF PUMPING.

In estimating the cost of the water it is necessary to take into account the original cost of the wells, pumps, engines, reservoirs, ditches, and other equipment, and the cost of operation, which includes fuel, oil, repairs, labor, and other items. In considering the original cost as a factor in the cost of a unit quantity of water it is most convenient to estimate the amount of deterioration of the plant in one year and to add this to the annual interest on the total amount invested in the plant. The sum should then be divided by the number of units of water pumped in a year. Professor Slichter advises that the charge for depreciation and repairs should be estimated at not less than 10 per cent of the first cost of the plant.

The following tables give the results of a number of tests of small pumping plants in the Arkansas Valley, Kansas,[b] and in the Rio Grande valley, New Mexico:[c]

Tests of small pumping plants, Arkansas Valley, Kansas.

Kind of pump.	Horse-power of engine.	Fuel used.	Price of fuel per gallon.	Total lift.	Yield of well per minute.	Cost of fuel per acre-foot[d] of water.	Cost of fuel for each foot that an acre-foot is lifted.
				Feet.	*Gallons.*		
No. 3 centrifugal	6	Gasoline	$0.22	22.1	272	$2.93	$0.13
Menge	10	...do	.20	15.5	394	2.90	.19
Two vertical, 6 by 16 inch cylinder.	1½	...do	.22	15.06	91	3.75	.25
Chain and bucket	7	...do	.21	17.0	540	1.37	.08
Do	2½	...do	.22	15.8	215	2.78	.18
No. 4 centrifugal	10	...do	.12¼	22.13	363	2.10	.09
No. 3 centrifugal	6	...do	.12½	17.60	198	1.67	.09
No. 14 centrifugal	80	Coal	[e]4.00	23.00	2,300	.85	.04
Two horizontal, 5 by 5 inch cylinders.	3½	Gasoline	.12½	21.7	96	1.09	.05
No. 4 centrifugal	5	...do	.12½	21.47	420	1.20	.06

[a] Water-Supply Paper U. S. Geol. Survey No. 184.
[b] Slichter, C. S., The underflow in Arkansas Valley in western Kansas: Water-Supply Paper U. S. Geol. Survey No. 153, 1906, pp. 55 and 56.
[c] Slichter, C. S., Observations on the ground waters of the Rio Grande valley: Water-Supply Paper U. S. Geol. Survey No. 141, 1905, pp. 34 and 35.
[d] An acre-foot contains 325,850 gallons of water, which is enough to cover 1 acre to the depth of 1 foot.
[e] Price per ton.

Principal data derived from tests of Rio Grande pumping plants.

Horsepower.	Fuel used.	Price of fuel.[a]	Total lift.	Yield per minute.	Cost of plant.	Interest and depreciation per hour.[b]	Labor and other cost per hour.	Fuel cost per acre-foot.	Total cost per acre-foot.
			Feet.	*Gallons.*					
10	Electricity	$0.05	38.93	378	$1,200	$0.108	$0.050	$3.43	$5.75
8	Gasoline	.14	30.70	269	800	.072	.120	2.26	6.13
5½	....do	.14	27.80	258	800	.072	.140	1.58	6.02
28	Crude oil	.03	36.70	938	3,000	.270	.180	.70	3.17
22	Gasoline	.14	41.45	1,325	2,200	.198	.150	1.43	2.79
15	....do	.14	35.87	658	1,500	.135	.150	1.73	4.10
5	....do	.17	45.58	131	1,200	.108	.120	3.73	13.20
12	....do	.17	40.30	658	1,200	.108	.150	1.34	3.47
21	....do	.17	40.45	725	1,800	.162	.150	2.52	4.87
8	....do	.17	26.85	648	900	.081	.120	1.48	3.16
12	....do	.17	34.77	325	1,200	.108	.150	5.14	9.57
8	....do	.17	36.05	271	800	.072	.120	5.10	8.95
10	Wood	2.00	34.16	351	1,200	.108	.180	3.47	7.91
28	Gasoline	.17	43.35	464	2,000	.180	.150	4.34	8.19
20	Wood	2.25	29.55	1,000	1,600	.144	.200	2.83	4.70
12	Gasoline	.17	23.89	837	992	.090	.090	1.04	2.21
12	....do	.17	35.26	191	992	.090	.090	5.80	10.90
12	....do	.17	32.36	750	992	.090	.090	1.16	2.46

[a] The price of gasoline given is for 1 gallon, the price of electricity for 1 kilowatt-hour, the price of wood for 1 cord.
[b] The depreciation and repairs are calculated at 10 per cent of the original cost and the interest at 8 per cent.

As near as it can be estimated from rather indefinite data obtained in regard to the plant of E. A. Von de Veld, northwest of Willard, the cost of fuel is about $3.50 an acre-foot. The water is here lifted with a 160-gallon chain and bucket elevator; the average lift is about 30 feet, and the price paid for the gasoline was reported to be 31 cents per gallon. According to these data, for each foot that an acre-foot of water is lifted the cost is about 11⅔ cents and the consumption of gasoline about 0.38 gallon. With the present capacity of the well, one-fifth of an acre-foot can be drawn conveniently in one full day; and on this basis if the plant is operated one hundred days it will consume $65 worth of gasoline and provide enough water to cover 20 acres to a depth of 1 foot or 10 acres to a depth of 2 feet. With gasoline bought at minimum wholesale prices and with more careful adjustments between the capacities of engine, pump, and well, the cost for fuel can be reduced materially, but the above figures are believed to be valuable in giving an idea of what has been done in practical work.

In a discussion of the cost of pumping in Arkansas Valley, Kansas, the following statement is made by Professor Slichter in regard to gas-producer plants:

If plants of from 20 to 50 horsepower are constructed, as I believe they will inevitably be in the near future, the cheapest power will probably be found in the use of coal in small gas-producer plants in connection with gas engines. These small gas-producer plants are largely automatic in action and can be operated by anyone. With hard coal or coke or charcoal at $8 per ton, the cost of power would be less than one-half cent per horsepower for one hour, or only one-fifth of the cost of power from gasoline at 22 cents a gallon. The writer anticipates no difficulty, therefore, in keeping the cost of water

below 60 to 75 cents an acre-foot for fuel, or below $1.25 to $1.50 per acre-foot for total expense.[a] Hundreds of such plants have been put in use in England during the past ten or more years, and they are in charge of unskilled labor. These gas-producer plants are used in England for a great variety of purposes, such as power for agricultural machinery and for small electric-light plants for country estates. They are used in as small units as 5 horsepower.

In this country the producer-gas plants have been in use for several years, and at the present moment they are fast taking the place of steam power in new plants. The cost of a producer plant and gas engine is about the same as the cost of a steam engine and boiler of same size when everything is included, but the cost of power from the producer-gas plant is very much less than that obtained from small steam engines.

In producer plants ranging upward from 100 horsepower a style of plant may be installed in which soft coal or lignite may be successfully used. This still further cuts down the cost of power. In fact, large plants of this type furnish the cheapest artificial power that has yet been devised. The saving is not only in fuel, but also in labor, as one man is capable of running a 300-horsepower plant.

In Estancia Valley gas-producer plants should be installed only after sufficiently large supplies of water have been developed to insure the success of such plants. A central power plant which will furnish an electric current for operating pumps on a number of farms may prove the most economical method of lifting water.

WINDMILLS.

Much has been written on irrigation with windmills. Their obvious advantage is that they utilize energy which is supplied by nature free of charge, but their original cost and the cost for oil and repairs are by no means negligible. Their greatest disadvantage lies in their dependence upon the wind, which may not blow at the time the water is most needed. They are best adapted to those parts of the valley where great depth to water or small yield permit irrigation on only a small scale.

The following data, taken from the Yearbook of the Department of Agriculture for 1907, will give some conception of what can be done with windmills. If the lift is increased or decreased, the amount of water that can be pumped will be decreased or increased in about the same ratio.

Work done by a 12-foot windmill.

Velocity of wind in miles per hour.	Height water was lifted.	Quantity of water pumped per hour.
	Feet.	*Gallons.*
6	56	89.76
8	56	269.28
10	56	501.16
12	56	718.08
17	56	1,271.00
18	56	1,353.88

[a] It should be remembered that this statement is made for the Arkansas Valley, where the water is near the surface.

Work done by windmills of different sizes.

Size and type of windmill.	Time.	Average wind velocity per hour.	Height water was lifted.	Quantity of water pumped.	
	Days.	*Miles.*	*Feet.*	*Gallons.*	*Acre-feet.*
16-foot, direct stroke	45¼	12.98	56	752,967	2.31
14-foot, back geared	45¼	12.98	56	666,991	2.05
13-foot, back geared	45¼	12.98	56	502,207	1.54
12 foot, back geared	45¼	12.98	56	408,854	1.25

VALUE OF CROPS.

Intensive cultivation of crops that yield large returns per acre would, of course, leave the largest margin after the cost of the water is deducted and would thus guarantee the surest success for irrigation by pumping, but present calculations must be based upon such ordinary field crops as can be depended upon in respect to both yield and market value. It is not intended here to enter into a full discussion of the various crops that might be raised, but rather to state a few facts which will give some quantitative basis for comparing crop returns with cost of water.

In regard to alfalfa, Samuel Fortier,[a] chief of irrigation investigations in the Department of Agriculture, states:

> Perhaps the most essential conditions for the production of alfalfa are abundant sunshine, a high summer temperature, sufficient moisture, and a rich, deep, well-drained soil. All of these essentials, save moisture, exist naturally in the arid region of the United States, and when water is supplied it makes the conditions ideal. * * * It is grown successfully in every State and Territory of the arid region, in localities which are not only widely separated but possess many radical differences in the way of rainfall, temperature, altitude, topography, and soil.

Mr. Fortier cites an experiment in Montana in which with 1 foot of irrigation water 4.42 tons of cured alfalfa per acre were produced, and with 2 feet, 6.35 tons, and adds:

> The results of this experiment seem to confirm the best practice of southern California, which may be summed up by stating that in localities having an annual rainfall of about 12 inches remarkably heavy yields of alfalfa may be obtained from the use of 24 to 30 inches of irrigation water providing it is properly applied.

C. A. Fisher[b] states that in the vicinity of Roswell, N. Mex., if 30 inches per year are properly applied, three or four crops of alfalfa may be cut, an average yield being 1 ton to the acre for each cutting. V. L. Sullivan, territorial engineer of New Mexico, estimates[c] that "the yield of hay (alfalfa) in this part of the United States is 2 to 7 tons an acre when grown under irrigation; an average of 5 tons is a conservative estimate, usually producing a net return of $10 per ton."

[a] Irrigation of alfalfa: Farmers' Bull. No. 373, U. S. Dept. Agr., 1909.

[b] Geology and underground waters of Roswell artesian area, New Mexico: Water-Supply Paper U. S. Geol. Survey No. 158, 1906, p. 28.

[c] Irrigation in New Mexico: Farmers' Bull. No. 215, U. S. Dept. Agr., 1909, p. 17.

Alfalfa seed is a valuable though rather uncertain crop, but it requires little water and could perhaps be raised to advantage after one crop of hay had been harvested.

Good crops of wheat, oats, and other cereals could no doubt be raised by irrigation, but a given amount of water would probably accomplish more if applied to beans, potatoes, or forage plants such as cane, Milo maize, and kaffir corn. Beets, melons, and vegetables are said to thrive well when moisture is applied, and some kinds of fruit could be raised.

BEST USE OF THE WATER.

The most hopeful view of the future of irrigation in Estancia Valley can not alter the conclusion that this valley must remain essentially a grazing or dry-farming region. Grazing yields very small returns per acre; dry farming may, if the elements happen to be propitious, yield vastly more. But the elements are and always will be capricious, and the farmer who must depend upon them entirely will necessarily have a precarious lot. The available water will, of course, be utilized in various ways, but it would seem that in the main it would be put to its best use when it is employed to supplement dry farming and stock raising.

In the first place, every farmer should irrigate a few shade trees, a small orchard, a small grass lawn, and a garden containing vegetables, shrubs, and flowers. These things will contribute much to the comfort of farm life, and, moreover, the garden will be of substantial value in supplying food for the household and in making it possible to tide over dry years. One of the very few examples of such irrigation at present found in the wide expanse of the valley is at the old Moriarty ranch. A small supply of water will provide these essentials. Indeed, there are few localities in the valley where enough water can not be obtained, or where it is so deep that the farmer can not afford to pump it for this purpose. For this kind of irrigation windmills will be useful, but it will be well to supplement them by small gasoline engines, so that the supply will not fail at the time it is most needed.

Where plentiful supplies of water are available within a comparatively short distance of the surface it may be profitable to install a larger plant and to irrigate a number of additional acres, on which can be raised alfalfa or forage, which will have a high value if fed to the stock on the farm in the winter or in times of extreme drought, when otherwise the stock would suffer severely; or a portion of the water can be used to raise for the market some more intensive crop, such as beans or potatoes, the proceeds of which will help to tide over years of failure in dry farming.

More than this, it may be that the ground water can be used to some extent to supplement dry farming directly. The damage to

crops is due perhaps less to the absolute deficiency of rainfall than to its irregularity and uncertainty. For example, enough rain may fall throughout the growing season to produce a fair yield except in one period of drought. If during this period the ground could be given one good wetting, success would be assured; but the wetting does not come and the farmer stands helplessly by to see his crop a total failure. It requires no argument to show that irrigation water at this critical time would have a value out of all proportion to that of its ordinary crop-producing power. It is also evident that a relatively small amount of water, considered for the entire year, would cover a large acreage; and it will be readily appreciated by the dry farmer who has gone through the hard experience of seeing his entire crop ruined that if, by means of the artificial application of water, only a small portion of his crop can be saved, it will be infinitely better than failure. There will, of course, be difficulties in developing a feasible method of combining irrigation and dry farming, but there appears to be no inherent reason why such a combination method can not be evolved.

The limits to the area in which the larger use of water is practicable and the limits to the amount of irrigation that is possible in any given locality within this area must be determined gradually by experience. The situation tends strongly toward an economical use of the water, and economy will tend in two ways to enlarge the scope of irrigation. It will reduce to a minimum the expense of pumping and the waste of the limited underground supply. The first concerns the immediate welfare of the individual; the second concerns the permanent welfare of the entire community. To a certain extent individual self-interest will here abet the public welfare, for the pump will not be operated except when necessary.

THE ALKALI PROBLEM.

The answer to the question whether a certain quality of water can be successfully used for irrigation depends largely on a number of related conditions, among which may be mentioned the kind of crops to be raised, the amount of alkali already in the soil, the natural drainage of the land or the ease with which artificial drainage could be established, and the cost and abundance of the water itself. If all these conditions are favorable, water containing large amounts of sodium sulphate and sodium chloride can be used with success, but if all or most of them are unfavorable the case is entirely different.

During the summer of 1902 T. H. Means, of the Bureau of Soils, visited certain oases in the Sahara Desert in eastern Algeria, in which waters carrying large quantities of soluble matter are used successfully for irrigation. Some of the vegetables successfully grown are

those considered sensitive to alkali, and yet they were being irrigated with water containing, in some places, as much as 8,000 parts per million of soluble salts, sometimes as much as one-half of these salts being sodium chloride. The methods used are described as follows: [a]

The Arab gardens are divided into small plots, about 20 feet square, between which run drainage ditches dug to a depth of about 3 feet. The soils being very light and sandy, this ditching at short intervals insures the most rapid and thorough drainage. Irrigation is by the check method, and application is made at least once a week, though often two wettings a week are deemed necessary. A large quantity of water is used at each irrigation. Thus a continuous movement of the water downward is maintained, there is little opportunity for the soil water to become more concentrated than the water as applied, and the intervals between irrigations being so short but little accumulation of salt from evaporation at the surface takes place. What concentration or accumulation does occur is quickly corrected by the succeeding irrigation.

It is essential to note that the successful use of this water depends entirely upon good drainage conditions and the application of large amounts of water. In the same paper, Means says:

The limit for concentration for irrigation water in the United States, even where only the most resistant crops are to be grown, has been placed by some authorities at 300 parts sodium chloride (common salt) or sodium carbonate (black alkali) and at from 1,700 to 3,000 parts of the less harmful salts, per million of water.[b] Those who place the low limit of safety for alkaline irrigation waters have taught that where water was badly alkaline irrigation should be sparing. They have not insisted on thorough drainage, and they have warned irrigators against too frequent irrigation. With such practices the limit of concentration which they set is probably high enough, and even then all except the most sandy soils or those with exceptionally good natural drainage would ultimately be damaged.

Writing upon the same subject, C. N. Dorsey says: [c]

When the soil contains a relatively large amount of salt and but little water containing much salt is frequently applied, the ordinary evaporation will increase the salt content of the soil to such an extent that crops can no longer survive, whereas if adequate drainage is provided and a large amount of water is used the excess of salt resulting from the evaporation of previous applications of water may be removed and the soil moisture be maintained at nearly the same concentration as the water supply.

The data given under "Soil" and "Quality of water" furnish a basis for a rather definite conclusion in regard to the feasibility of irrigating in the alkali area of Estancia Valley. The samples of soil that were analyzed have a high alkali content, and the water in the same region is rich in dissolved chlorides and sulphates. Within the area of saline shallow water (that is, the area in which the shallow ground water has a chlorine content of more than 1,000 parts per million), 9 samples of deeper water were tested, and the average chlorine content of these 9 samples was found to be 595 parts per million. On the assumption that all the chlorine is in equilibrium

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[a] Means, T. H., The use of alkaline and saline waters for irrigation: Bureau of Soils Circular No. 10, U. S. Dept. Agr.

[b] In the original paper the quantities are expressed in parts per 100,000 of water.

[c] Reclamation of alkali soils: Bull. Bureau of Soils No. 34, U. S. Dept. Agr., 1906, p. 11.

with sodium, the average content of common salt would be 982 parts per million, or more than 2,500 pounds per acre-foot. By the time 10 feet of water would have been applied to a field, 25,000 pounds of common salt would have been placed on each acre irrigated, which would be 0.625 per cent of the soil if concentrated in the first foot, or 0.156 per cent if distributed through the upper 4 feet.

If good drainage conditions could be established and the water could be applied unsparingly, then, by the use of the deeper water, the alkali now in the soil and that introduced by the water could be disposed of by leaching it downward and draining it away. Unfortunately the natural drainage is poor and the expense of establishing artificial drainage would be too great. Unfortunately, too, the liberal use of water would be prevented by the limitations of the supply and the cost of pumping. In view of these facts the general conclusion can not be avoided that in the most alkaline portion of the central flat irrigation by pumping from wells is not feasible, and it becomes necessary to advise against expenditures for installing pumping plants within this area. A like caution should also be given for a wider region having poor drainage, water of intermediate chlorine content, or soil that shows any alkali symptoms, lest, in the course of time, the sparing application of well water will result in an injurious accumulation of alkali.

SUMMARY.

The conclusions in regard to irrigation with ground water can be briefly summarized as follows:

In spite of the high cost of fuel, if the water is lifted in the most economical way and is wisely used, pumping for irrigation can under favorable conditions be made profitable. The underground supply is too small to irrigate more than a small part of the valley, but it is sufficient to add materially to the prosperity and comfort of the people. Even where the depth to water is great, the irrigation of a garden, lawn, and orchard will generally be feasible. In the central area, however, the presence of alkali may seriously impair the quality of the water or may prohibit its use. Taken as a whole, the water of Estancia Valley is a valuable resource that should be developed, but its development should be conducted carefully and with full cognizance of the inherent limitations.

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